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ABSTRACT

The three papers in this book treat the experimental literature on eye movements in reading and information processing to determine what factors might be manipulated to improve reading efficiency. The first paper discusses control models of eye activity in reading, research data concerning eye activity with reading material, and future directions for research in this area. The second paper examines the notion of processing efficiency in reading, reviews a model that deals explicitly with automatic information processing in reading, discusses relevant research, and suggests procedures for studying the efficiency of reading skills. The final paper critically reviews the Human Information Processing (HIP) approach to reading, assessing its utility both as a theory of how people read and as a possible guide to pedagogical practice. (GW)

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ira series on the development of the reading process

MODELS OF EFFICIENT READING

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
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Foreword

It is particularly fitting that the International Reading Association should publish this *Series on the Development of the Reading Process* for the volumes in this series exemplify the value of reading—the value of the printed word. The Series originated in a four-week summer institute at the University of Delaware. Those fortunate people who were able to participate in the institute counted it an enriching experience. How does one share such an experience at a reasonable cost with thousands of others who will wish they might have been present to participate? Through the medium of print. In this IRA series, participation in that unusual institute is available to all interested readers.

The volumes in this series represent more than just a series of papers presented at the institute. They incorporate ideas raised in the discussions at the institute and new developments interpreted through perspectives engendered by the institute.

This *Series on the Development of the Reading Process* deals with important basic issues that are fundamental to understanding the changing nature of the reading process as both the process and the child develop. In the literature on reading, these issues—such as the development of the child's cognitive abilities, the development of the child's semantic system, the child's changing conceptions of language, and the developing relation between listening and reading—are often referred to knowingly as if they are well understood or as if mere reference to them will prove a point. In this series, however, each volume deals with one such basic issue in a comprehensive way and specifically in relation to learning to read.

The person with the vision to develop the institute and with the wisdom and commitment to see that the fruits of the institute were made available to others is Frank B. Murray, editor of this series. The International Reading Association and all who value a deeper understanding of the development of the ability to read are indebted to him for his vision and his labor.

WALTER H. MACGINITIE

Preface

In this fourth monograph of the series on the development of the reading process, the efficiency of the process is examined. The discipline of psychology, which will eventually describe the mental mechanisms of reading, has not found an adequate model of the mind. Psychology can be said to be in its pre-Galilean phase of development. For example, Aristotelian psychology provides a model that still has contemporary plausibility while its physics has obviously been replaced by more sophisticated and powerful models. Throughout its relatively short history as an experimental science, psychology (having no broad conceptual base of its own) has borrowed major concepts from other disciplines at various points in its evolution. Borrowing initially from atomic physics and Lockean philosophy, psychologists searched for the mental atoms linked by the glue of Aristotle's principles of association. Later, under the influence of Darwin, psychology turned to an exploration of the mind's functions rather than its "atomic structure" because whatever its structure its functions would still have to be explained. The rapid advances in physical field theory thereafter found their counterparts in Gestalt psychology and the discovery of topology in mathematics lead again to considerations of structure— this time of the "topological" structures of personality. More recently the Bourbaki group of logical-mathematicians provided Piaget with a model for logical reasoning, and advances in linguistic theory by Chomsky have contributed to the contemporary notion of the mind as an innate system of plans and rules.

The development of computer science has led to a more general model of the mind as an information processor and to the notion that the mind and the computer share in common a number of illuminating features. If the mind were modeled after a computer program, a clue to the reading process could be had in the analysis of the features of a computer-like program that would simulate reading. This program would be, in fact, a

good candidate for a psychological theory or model of reading. Tests of the model might focus on how the mind acquires information and how long it takes to process it. This approach inevitably leads to studies of the eye's movements as a clue to how information in print is acquired initially and to studies of the exact intervals of time it takes for the mind to execute the various "program" routines and subroutines alleged in reading.

The papers in this book by Karen Cohen, Richard West, and George Marsh treat the experimental literature on eye movements in reading and information processing to determine what factors might be manipulated to improve the efficiency of the reading skill.

The series is organized around the notion that the child's reading behavior, among other things, is a developmental phenomenon. This means that, like other developmental phenomena, there are certain necessary and sufficient conditions for it and that it changes both quantitatively (it becomes faster and more efficient) and qualitatively (different and more complex models are needed to explain it) as the child ages. The series will examine the development of reading from the perspective of the perceptual, cognitive, neurological, and linguistic prerequisites for it; specific factors in its acquisition; and factors which lead to the enhancement of the reading skill once it has been acquired.

During the summer of 1974, the Society for Research in Child Development, with the support of the Grant Foundation of New York, sponsored a four week interdisciplinary institute at the University of Delaware on Reading and Child Development. The thirty-three institute faculty were researchers in the disciplines of psychology, psychiatry, education, linguistics, neurology, sociology, and the law. Each spent from three to five days at the institute, both formally and informally presenting the applications of their research to the field of reading.

The institute participants were advanced doctoral students and postdoctoral faculty from various disciplines who had an interest and commitment to research in reading. They were present for the full four weeks, and some of them are contributing authors to this IRA *Series on the Development of the Reading Process*. Each title in the series is based upon

aspects of the institute proceedings, intensive discussions between participants and faculty, and each author's particular perspective.

The success of the institute, upon which this series is based, was due to the energies and talents of many people. In addition to the dedication of the participants, faculty, and administrative staff (whose names appear elsewhere in this issue), the staff of Clayton Hall and the Department of Educational Foundations of the University of Delaware, and the members of the Long Range Planning Committee of the Society for Research in Child Development contributed substantially to the planning and execution of the institute. Finally, the series itself was greatly improved by the editorial assistance of Lloyd Kline and Faye Branca of the International Reading Association.

Frank B. Murray

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The International Reading Association attempts, through its publications, to provide a forum for a wide spectrum of opinion on reading. This policy permits divergent viewpoints without assuming the endorsement of the Association.

Eye Activity in the Study of the Reading Process[1]

KAREN M. COHEN[2]
University of Denver

Reading is the act of translating printed information into meaning. Such an activity involves the coordination of numerous subskills by the central nervous system. The only universally accepted, external manifestation of these rapid, higher-order processes in normal, silent reading is the activity of the eyes. It is no small wonder, then, that eye movements and their pauses have enticed psychologists and educators in their attempts to understand the reading process. This interest, which has fluctuated sinusoidally over the past century, has led to the specification of many eye-related parameters in reading and to the development of sophisticated technology for monitoring ocular behavior. These achievements as well as hypotheses to guide future investigation will be presented under the following headings: 1) Control Models of Eye Activity, 2) Eye activity with Reading Material, and 3) Future Directions for Research.

Control Models of Eye Activity

Several models have been postulated to account for the psychological control of the eye movements from fixation to fixation during reading. Rayner (1974) collapses these positions into three categories: constant pattern, stimulus control, and internal control.

The constant pattern model asserts that the eyes follow a regular, rhythmical pattern as they move over the text. Oculomotor habits result in rather mechanical movements of approximately equal extent. This position was first expressed by Javal in 1897. Although Huey (1908) demonstrated with more precise measurements that the extent of eye movements over a page could be quite irregular, the constant pattern

notion still flourished. Additional support for this regularity of movement probably came via influence from Westheimer's work (1954). He demonstrated that eye movements were ballistic in nature; i.e., their direction and distance seemed to be determined prior to actual movement. In fact, once the "plan" for movement had been completed, the course of the movement was unalterable. Though the ballistic nature of individual eye movements has been confirmed, it does not necessarily follow that the entire "plan" for oculomotor behavior is programed immediately upon confrontation with printed material. In fact, there is little empirical evidence to support this rhythmical, constant pattern position.

The second model, stimulus or local control, implies that the eye is controlled by visual characteristics of the stimulus and the information which is acquired from the visual periphery. Numerous visual scanning studies (e.g., Mackworth & Bruner, 1970; Yarbus, 1967) have demonstrated the apparent use of peripheral information to guide eye movements since adults tend to fixate the most "informative" elements of a display. Research with reading material (McConkie & Rayner, 1973) further supports the position that information obtained from the periphery is useful in redirecting fixations. No exhaustive list of cues from the periphery has yet been compiled, and it is unlikely that stimulus information alone could determine eye movement patterns since we find large individual differences in eye activity with the same stimulus materials (Buswell, 1922).

The third model relinquishes control of eye activity to central processes. The internal control implied here is a function of the amount of processing achieved, the information needed, and the difficulty experienced by the reader. Psycholinguistic guessing models (Goodman, 1970) and hypothesis-testing models (Levin & Kaplan, 1971) of reading fall into this camp. The reader makes use of contextual information and linguistic structure to anticipate subsequent information in the text. Though this approach helps the reader in hypothesizing what may come next, there appear to be no aids in determining how far along a line he should move his eyes.

Clearly, any of these models considered separately appears to be inadequate for controlling eye movements.

Kolers (1974) has hypothesized a variant of the ballistic eye control model in which a sensitivity or gain control is added to account for variations in stimulus materials and task conditions. Once the system is attuned to the particular textual information, the ocular behavior follows a consistent pattern akin to any well-practiced motor skill. In contrast to an overarching plan for eye movements during reading or a fixation-by-fixation plan, it has also been suggested that subplans for executing a small sequence of eye movements are established periodically. These subplans are interruptable or amendable based on information processed during fixations within the sequence. More comprehensive approaches which have incorporated both stimulus control and internal control models have been posited by Hochberg (1970) and McConkie (1974).

For Hochberg, reading implies both intentional behavior and attention to meaning inherent in the text. Thus, he posits two factors determining eye location: cognitive search guidance and peripheral search guidance. The cognitive components include the meaning attained from the previous fixation as well as the appreciation of contextual redundancy and linguistic cues in the text. The peripheral components refer to visual information about the physical characteristics of the stimulus (e.g., word shape, length, spaces). The integration of information from these two sources leads to hypotheses about the information to be obtained in the upcoming fixation; the reader then moves his eyes to test such hypotheses. McConkie's model (1974) differs from Hochberg's both in the specificity of kinds of information utilized from the periphery and more importantly, in the reason for eye movement. McConkie emphasizes the information-seeking component, as opposed to the hypothesis-testing model: the reader moves his eyes to the most informative areas of the text in order to add input to the expectations he has derived from the previous fixation. Both these positions assert that redirection of fixation is dependent upon a complex interaction of semantic and syntactic cues, hypotheses or expectations from previous fixations, and peripheral visual cues. This combination of information enables the reader to control more accurately the locus of his next fixation as well as alter the duration of each fixation. Such an integrative position is

essential in recognizing the complex interaction of processes which control eye activity. In discussing the facts and fallacies about eye activity and reading, Taylor (1965) summarized that:

> Eye movements are neither the cause nor the effect of good or poor reading. The eyes do not dictate to the mind what it shall understand; neither does the mind dictate to the eyes where they shall look. Instead, there exists an interaction and interdependence between the oculomotor activity and the central processes, each function indirectly influencing the other (p. 199).

Eye Activity with Reading Material

Before the turn of the century Professor Javal at the University of Paris began exploring the nature of eye movement patterns in reading.[3] Javal is credited with the observation that the eyes move in jerky, rapid jumps separated by eye pauses over the lines of print; he labeled this action "saccades" which is the term still used today to refer to the quick movements of the eye. Working by means of direct observation with a mirror and magnifying glass, he also noted that the eyes stop approximately every ten letter spaces and thus concluded that this area represented the span of vision during one eye-pause or fixation. From this methodologically crude beginning, evidence has continually accumulated about the nature of eye movement patterns in reading. Though techniques for monitoring eye activity have become increasingly sophisticated, the basic parameters of interest have remained constant: location, duration, frequency, and sequence (directionality) of eye fixations. In this section, the data on eye activity in reading are discussed in relation to the following questions:

1. What are the general characteristics of eye activity during reading?
2. How much does the eye "see" in a single fixation?
3. Are there particular loci where fixations fall?
4. Are there age differences in eye activity during reading?
5. Are there age differences in eye-voice span during reading?

6. Are there individual differences in eye activity during reading?
7. Is there a relation between eye activity and reading ability?
8. What is the relation between oculomotor training and reading?

What are the General Characteristics of Eye Activity During Reading?

As Javal observed, the eyes move in a saccadic fashion, roughly paralleling the horizontal lines of text. Additionally, Erdmann and Dodge (1898) reported a regularity in the number of pauses per line for the same individual reading familiar material. They also noted that the first pause was well within a line, and the last fixation on the same line was left-indented to an even greater extent than the first pause. This latter phenomenon of reduced fixations toward the end of a line was explained as a joint function of the previous context and of the length of time the information was in "indirect" or peripheral vision—explanations which are recognized as cogent today. The first fixation, when preceded by a return sweep from the right side of the page, was often followed by a regressive eye movement to the left of first fixation. This regression was viewed as a correction for imperfect convergence of the eyes following the long jump and the necessary divergence during fixation (Woodworth, 1938: 723; Tinker, 1958: 218). Contrary to Javal, Huey (1908) and Woodworth (1938) both reported that the length of each eye movement between fixations over a line could vary and that the first fixation on a line was often of longer duration than others since the initial portion of the line had not been seen in peripheral vision prior to the fixation.

Though the eye is moving rapidly during reading, less than 10 percent of reading time is used for the actual mechanics of ocular movement (Tinker, 1958). Dodge (1900) and later Dearborn (1906) reported that lateral eye movements took approximately 22 msec. while the return sweeps averaged 40 msec.; these time parameters of oculomotor functioning were stable across fatigue and speeded conditions (Tinker, 1936).

Duration of fixation is apparently more variable though most researchers report a minimum average of 200-250 msec. duration for adults under familiar reading conditions (Buswell, 1922). The duration of fixations may vary within a line, across different types of material for the same reader, and between individuals. These pauses in eye activity have long been reported as the time during which information is processed or organized and decisions for refixation are made as well as the reaction time for convergence and divergence of the ocular system.

Contrary to Holt's hypothesis (1903) that vision was impossible during the movements of the eye, Dodge (1905) and Huey (1908) demonstrated that clear vision was simply reduced while the eye was in flight. They rejected the notion of central or peripheral anaesthesia or inhibition during eye flight. Instead, they speculated that the phenomenon was a result both of the persistence of the previous sharp fixation overriding the fainter and briefer information passed over the retina during flight and of our abilities to filter out information that has already been deemed meaningless or less relevant prior to the initiation of the eye movement. More recent studies (Latour, 1962; Volkmann, 1962; Volkmann, Schick, & Riggs, 1968) have shown that the threshold sensitivity of the visual system appears higher during the actual eye movement. Hence, the reduced sensitivity tends to minimize the amount of retinal blur one would expect from the rapid movement of the eyes, and ultimately increases the amount of time for processing information from a previous fixation.

The precise number of fixations per line varies with length of line, ease of the material, and skill of the reader (Buswell, 1922). Number of fixations is often inversely related to duration of each fixation for the same individual under comparable conditions. Increasing the length of the eye pause supposedly provides more time for deriving meaning from the fixated information and for analyzing peripheral information which results in a potentially larger jump for the next fixation. The result, then, of increasing average fixation duration when a finite amount of material is presented to the reader is a reduction in the number of fixations necessary to traverse and understand the passage. However, when difficulty in grasping meaning or understanding a particular word is encountered,

both number and duration of fixations may increase. In this case, small regressive eye movements are common.

These facts which have accumulated for over a century reflect general parameters of the oculomotor skill involved in reading. Variations in these eye movement and pause patterns are often utilized as indices of the reader's central processing of information under various experimental conditions.

How Much Does the Eye "See" in a Single Fixation?

Though this question primarily involves the *perceptual* span of recognition, the amount of information a reader "sees" in a fixation may also vary as a function of the structural properties of the eye. After early observations that a reader did not fixate on each letter in print, researchers began to explore questions about the range of useful information located in the visual periphery. A perimeter method was used by Korte (1923) in which letters or words to be recognized were brought in gradually from the periphery toward the reader's central fixation point. Though this method required steady fixation by the reader, Korte found that single letters could be recognized farther out than words. Part of the problem with words seems to be the masking or interference effects of the end letters on the interior letters in words. Tachistoscopic methods, in which visual information is flashed at sub eye-movement duration were employed as early as 1907 by Ruediger and by Hamilton. The former researcher found correct recognition of letters as far out as 7.7 degrees visual angle at a 50 msec. exposure duration while the latter author found that 1-2 words could be recognized in a single fixation. Hamilton also found that readers made guesses about words they had not foveally fixated. Even individuals reading horizontally or vertically aligned Chinese passages covered about two words per fixation despite the very different structure of the Chinese language and its printing from English (Shen, 1927). The spatial extent of each fixation was smaller (slightly more than one degree) than that found in reading English; this result was attributed to the shape and arrangement of Chinese words. Taylor (1965) also reported a span of vision in reading English of approximately 4-5 letters about a fixation point with a

growth in span of recognition from 1.1 words to 2.5 words per fixation from childhood to adulthood. His estimates were derived from calculating the number of fixations per 100 words of text.

Much of the evidence for the breadth of vision within a single fixation rests upon calculations similar to Taylor's or data from tachistoscopic recognition procedures. Both methods seem inadequate for answering the initial question posed here. The calculations are confounded by the rich contextual information available to the reader which obviates the necessity of fixating all the printed information in either foveal or peripheral regions of the eye. Contrariwise, the tachistoscopic paradigm interrupts the dynamic activity in reading and may reflect very different static operations. Though the stimulus time parameters employed are of sub eye-movement duration, one cannot be certain what stimulus time parameters are comparable to processing during a fixation while reading: we still do not know how much time is utilized during a fixation for processing information within the fixation boundaries and for resettling the eye and planning the subsequent fixation. Though the results have appeared consistently and may be valid, one should recognize the limitations of the experimental methods used to derive the recognition span estimates.

More recent research (McConkie & Rayner, 1973; Rayner, 1974) has overcome some of these problems by using an on-line computer system which presented a given amount of text dependent upon the location of the reader's eyes. The reader's eye fixation point was surrounded by a "window" of a given number of letter spaces and as the reader moved his eyes, the window of informative letter characters and spaces moved. In their experiments, McConkie and Rayner systematically varied the nature of the background characters as well as the size of the window. They concluded that information for word versus nonword distinctions could be made only within 4-6 character spaces from fixation while information about specific letters and word shape could be distinguished as far out as 10-12 character spaces from fixation. While their variations in background may have disturbed the natural reading process, their estimates seem to be the most reliable to date. Clearly, what is "seen" extends far beyond the foveal region of fixation and probably serves as an aid in determining the locus of the next fixation.

Are There Particular Loci Where Fixations Fall?

Using data from Buswell (1922) and Dearborn (1906), Woodworth (1938) calculated frequency of fixations on particular parts of the stimulus display during reading. His general conclusion was that:

> The eye seems to have no predilection for landing on any special part of a word or type of letter or length of word, though, if anything, it avoids capital letters and falls a little disproportionately upon the short words (p. 729).

Nodine and Lang (1971) have utilized eye recording techniques to address questions about the relation between visual scanning and reading. Kindergarten and third grade children were asked to make same/different judgments about four-letter pseudowords in which the middle letters were reversed (e.g., ERDI-EDRI). The middle letters also varied with one another in confusability. Their data showed that younger children looked more within a single pseudoword while older children made more comparisons between the critical interior letters of each pair.

Nodine and Steuerle (1973) later investigated differentiation of graphemes among kindergarten, first, and second grade children. While all age groups focused more on target than nontarget areas, the older children made fewer cross comparisons prior to judgment. The data indicated that, although older children did not necessarily make use of all of the distinctive feature information in the graphemes, they more heavily weighted those areas than did younger children.

Several researchers (Woodworth, 1938; Buswell, 1920; Judd & Buswell, 1922; Mackworth, 1974) have found that the number of fixations increases on an area of text which poses difficulty for the reader. The difficulty was often attributable to an unfamiliar word or to the reader's inability to comprehend a portion of the text. The increased number of fixations was particularly evident for vocabulary problems whether the individual was reading silently (Buswell, 1922) or aloud (Mackworth, 1974).

Mehler, Bever, and Carey (1967) more recently postulated that the reader concentrates his fixations on the first half of each immediate phrase constituent in a sentence. These findings prompted Wanat (1972) to monitor changes in eye fixations as a function of linguistic variables. He found a

greater proportion of forward fixations falling in the area of the sentence's immediate constituent analysis (e.g., left-embedded sentences contained a relative clause modifying the subject), though total number of fixations for sentences differing in immediate constituent analysis was equal. He also varied structural predictability through use of nonagentive and agentive nouns; he found more regressive eye fixations in the area of the nonagentive noun, which represented a violation of linguistic expectancies. Wanat's data also indicated that the main verb in a sentence was usually fixated and, thus, its location determined much of the reader's allocation of visual attention.

Though forward fixations of the eye in regular, silent reading may be rather nonspecific in their location, the relative accuracy in regressive eye fixations to areas of vocabulary or semantic difficulty is very impressive. This activity implies that spatial and temporal information is stored along with meaning, as the eye traverses the text in reading (Judd & Buswell, 1922; Kolers, 1974).

Are There Age Differences in Eye Activity During Reading?

Several researchers who have photographed the eye activity of children while reading have reported similar results: with increasing age, there is a corresponding decrease in the number of forward and regressive eye movements and in the mean duration of fixation (Buswell, 1922; Gilbert, 1953; Taylor, 1965). Taylor was perhaps the most thorough of these researchers, testing more than 1,000 children at each grade level from first grade through college; he also used stimulus materials appropriate for each grade level and had a criterion level for his subject pool of at least 70 percent comprehension of the assigned text. The specific trends he found were: decreasing number of fixations and regressions per 100 words (224→90 and 52→15); increasing mean span of recognition (words/fixation, .45→1.11); decreasing duration of fixations (.33 seconds→.24 seconds); and increasing rate of comprehension (words/minute, 80→280). From the accumulated data, it seemed that the pattern of eye activity stabilized by fourth or fifth grade. Tinker (1958) refuted Ballantine's conclusion

(1951) that difficulty of materials did not affect eye movement patterns on the grounds that the most difficult text Ballantine used was at the same grade level as the children tested. Morse (1951) found that, while older children were more efficient in their eye movement patterns than were younger children, they also did not change their patterns in accordance with the difficulty of the material. Tinker considered this inflexibility in adjusting to differential difficulty as a sign of immaturity in reading which could hinder subsequent efficiency in different reading situations. As a warning against merely recording eye movements without checks on comprehension, Tinker noted a study by Dunn (1954) in which eye activity of retarded and normal boys of the same mental age was the same in fixation frequency, regressions, and rate of reading. Only comprehension measures distinguished the groups!

In unraveling age differences, several researchers have tried to separate basic oculomotor skill per se from reading in general. Gilbert (1953) had students in grades one to nine and in college read simple prose and digits. Though he concluded that simple motor activity (manifested in reading digits) was related to performance in reading prose, Tinker (1958) did not believe that Gilbert's results adequately teased apart oculomotor skill from actual reading: "Reading digits is reading... digits are symbols for words" (p. 220). Basically, Tinker rejected many of Gilbert's conclusions because of faulty assumptions inherent in Gilbert's experimental design and test materials.

Stennett, et al. (1972-1973) tried to separate oculomotor skill from cognitive activity in reading with a similar digit-reading task; however, they were interested in the performance of different age groups in speeded and unspeeded conditions. In the condition where speed was stressed, variance was reduced for all ages on number of forward and regressive fixations and average duration of fixations. This speeded condition, which they interpreted as a simple oculomotor skill, also eliminated age differences, except for mean duration which decreased with age. Since fixation duration has often been interpreted as the time for processing information, their results imply that age differences in reading are a function of the central level of processing and not of the peripheral level in terms of oculomotor skill. This conclusion is consonant with

other findings in the psychological literature in which age differences in eye activity and scanning behavior seem to vary as a function of comprehension of task requirements and familiarity with stimulus materials (see Cohen, 1974 and Day, 1975 for reviews).

Are There Age Differences in Eye-Voice Span During Reading?

The eye-voice span represents the distance or time between the location of the eye fixation and word being pronounced during oral reading. Measurements of this span were made as early as 1897 by Quantz and 1917 by Gray. The average distance the eye is ahead of the voice for an adult is 4.4-5.4 words, though the measure is somewhat confounded by adults' abilities to guess what may or may not have been in the visual periphery. More exacting studies of eye-voice span have become possible with improved technology (Buswell, 1920; Mackworth, 1974). Buswell's results indicated that the eye-voice span increased with age and was longer for the good reader than for the poor reader. The span, however, may be reduced to zero when a particular difficulty is encountered—that is, the eye does not move ahead until meaning is ascertained. In terms of word length, the eye-voice span for adults may vary from 0 to 8 words; in terms of time, it is approximately 1-2 seconds.

The mere existence of an eye-voice span indicates that the reader is simultaneously performing many operations—perceiving visual input, translating information into meaning, articulating words, and planning subsequent eye fixations. Though reading aloud may help in diagnosing problem areas and in analyzing eye fixation records (Mackworth, 1974), one should note that reading orally requires that the individual pronounce every word, an activity he is unlikely to do, even if he subvocalizes most of the text in silent reading (McGuigan, 1970). The slow down in reading rate to one's speech rate is also manifested by additional fixations. The irony is that eye-voice span was originally introduced to help monitor processing time for getting the meaning from visual input. Cooper (1974) has utilized the speed and accuracy of the oculomotor system to demonstrate comprehension of aurally-presented information;

he monitored subjects' eye movements and fixations on pictures while a story was being read to them. Perhaps adaptations of his techniques are possible in order to investigate the processing time for translation from visual input to meaning in reading; at present, it seems that eye-voice studies which necessarily invoke oral reading may not provide the data needed to understand the processes involved in silent reading.

Are There Individual Differences in Eye Activity During Reading?

Most researchers agree that patterns of eye activity differ among individuals of the same age and reading ability (Gilbert, 1953; Morse, 1951; Dixon, 1951; Ballantine, 1951). While Taylor (1965) reported characteristic individual patterns over similar material and only slight changes with different subject matter, Judd and Buswell (1922) found greater differences with a range of difficulty in stimulus passages. Tinker (1958) reported:

> Examination of all the literature suggests that variation in eye movements occurring with variation in subject matter is due largely to differences in the difficulty of the material or to changes in the purpose for which the reading is done rather than to differences in subject matter as such (p. 222).

When materials were equated for difficulty and familiarity, researchers did not necessarily find different eye movement patterns for different types of materials. Tinker (1958) stressed the importance of flexible eye movement patterns in order to adapt to different difficulty levels and kinds of stimulus materials. For Tinker, this flexibility is the hallmark of the mature reader.

Woodworth (1938) reported differences in eye activity (though not necessarily for the same individual) over a range of tasks including proofreading, spelling, objective examinations, numbers, formulae, addition problems, foreign languages, and music. The individual nature of patterns of eye fixations found in these reading studies is consistent with the individual variation found by Yarbus (1967) when adults viewed pictures, though reading material helps to organize the eye movements along a horizontal dimension. Despite individual variation,

however, there is generally more consistency in number and duration of fixations within age groups than between them.

Is There a Relation between Eye Activity and Reading Ability?

As just mentioned, Tinker associated flexibility in eye movement patterns with mature reading. A continuum of flexibility of reading habits appears to be associated with general reading ability (Laycock, 1955). Taylor (1965) claimed that better readers showed greater oculomotor efficiency, generally made fewer fixations and regressions, had larger spans of recognition, and had longer durations of fixation in proportion to span of recognition than did poorer readers. Mackworth (1974) used a Reading Aloud Fixation Time (RAFT) score to distinguish good and poor readers and to identify the locus of a poor reader's problem (e.g., a particular vocabulary word).

Unfortunately, these eye movement indices probably represent an effect, rather than a cause, of poor reading. Woodworth (1938) underscored this point by his finding of low correlations between reading ability and ability in other visual tasks. Even fatigue from six hours of reading appeared to have no large effects on an individual's eye activity (Carmichael & Dearborn, 1947).

Mackworth's research (1974) indicates that "line of sight" (eye fixation) recording may help to distinguish good and poor readers and, more importantly, to monitor gradual progress in reading ability. Care must be taken, however, to recognize that eye activity (greater number of forward and regressive eye movements, which characterize the poor reader's behavior) does not specify the reason for a poor reader's deficiency; in fact, mildly "deviant" eye activity may mask his problems of comprehension and linguistic expectancies and lead teachers and parents to treat the symptoms, not causes, of his reading difficulty.

What Is the Relation between Oculomotor Training and Reading?

This very question spurred Taylor (1965) to review the eye movement and reading literature when he learned of

oculomotor training exercises in his daughter's classroom. He cited considerable evidence to dispel the myth that training designed to widen one's span of recognition would necessarily result in improvement in reading. The fallacious assumption is that speed of reading is synonymous with reading ability. Moving the eye along at a faster rate does not indicate improvement in reading if such speed reduces comprehension. Even speed reading courses are designed to teach individuals to "skim" passages for main ideas and to utilize linguistic redundancies and expectancies; hence, speed at the expense of meaning in these courses is not considered a reflection of reading improvement.

Glock (1949) used different training procedures to study their effects on eye movements during reading. A technique that paced the eye movements in accordance with particular phrases showed no greater improvement in eye activity than techniques which exposed two lines simultaneously or which motivated students to read quickly for comprehension.

Tinker (1946, 1958) reported several other training studies which showed changes in eye movement patterns as a function of experimental training. When appropriate controls were included, the results indicated "improvement obtained by such training, with or without elaborate apparatus, is no greater than that resulting from well-motivated reading practice alone" (1958: 225).

The issue of oculomotor training to improve reading ability is far from buried. Only recently, national organizations for pediatricians and for ophthalmologists have released a joint statement denouncing the utility of visual training in solving learning disability problems. In the Stennett, et al. study (1972-1973), the correlations between eye movement patterns and reading test subsets were too low to permit substitution of their latter measures for eye movement data. Their results, however, implied that children learning to read probably have most of the basic oculomotor skills involved in scanning a line of information, hence vitiating some of the current controversy of extreme positions between optometrists and ophthalmologists (Flax, 1973; Benton, 1973). The former group has stressed training of oculomotor muscles as a remedy to many learning disabilities in children; this position has been renounced by the latter group as a false panacea for learning disability problems. Only when there is a well-defined

oculomotor deficiency should training of eye muscles and movement per se be seen as a means of aiding reading performance.

In this section, the data on eye activity during reading has been presented. The number of parameters that can be examined is few and, as most researchers pointed out, eye activity is principally an external manifestation, albeit limited, of the complex central processes which translate visual input into meaning. Tinker (1958) concludes his review pessimistically, noting that:

> The study of eye movements in reading is to some degree reaching the stage of diminishing returns. Relatively few of the recent experiments deal with fundamental problems. Too many investigators appear to be unfamiliar with the literature in the field. In several instances findings are reported as new when in fact they are the same as discovered and reported earlier. The future study of eye movements in reading does not appear to be too promising (p. 229).

To repeat studies designed to measure eye activity per se would no doubt fulfill his prophecy. However, to utilize eye movement technology and data to address questions about the acquisition of meaning from visual experience seems to have unlimited potential. Viewed from this perspective, in fact, one would find researchers turning full circle toward their initial query into the reading process: how we translate visual symbols into meaning.

Future Directions for Research[4]

It is evident that there have been numerous reports of the most elementary characteristics of eye activity during reading. It is now necessary for the researcher to formulate ways to utilize ocular parameters as dependent variables in addressing questions about information usage during a single fixation, about guidance of subsequent eye movements, and about extraction of meaning from visual input.

Information Usage During a Single Fixation

Previously cited research by McConkie and Rayner has probably yielded the most precise data on the kinds of

information dealt with during a single fixation. Through alteration of background material and replacement of words in text, they have demonstrated that semantic distinctions (word versus nonword information) can be made within an area approximately the size of the fovea (1-2 degrees visual angle) while specific initial and final letters and word-shape information can be obtained from the peripheral visual field (within 5 degrees of visual fixation). Word length is ascertained out to approximately 4 degrees of visual fixation. Blank spaces and beginnings of sentences are rarely fixated. These results demonstrate the use of much more than simple letter information during a single fixation.

With the much cruder technique of brief stimulus exposures, Cattell (see Huey, 1908: 72-73) concluded that we read by word or phrase wholes, and certainly not letter-by-letter. This work first demonstrated the "word superiority effect": he found that it took less time to recognize a word than both a single letter and two or three unrelated letters. A more recent demonstration of the use of linguistic cues inherent in words was conducted by Barron and Pittenger (1974). They presented subjects with word pairs of three types: high frequency English words, orthographically acceptable pseudowords, and nonword letters strings (*dance, cande, dncae,* respectively). For "same" judgments, they found mean reaction times for judgments to be ordered such that real words were faster than pseudowords and pseudowords were faster than nonwords. These results indicated that subjects used semantic information in addition to graphemic information in word perception.

Along different lines, both Neisser (1969) and Willows (1974) addressed the questions of usage of information from the visual periphery. Willows had subjects read paragraphs printed in one color of ink, while words in another color of ink were occasionally located above the lines of text. Her subjects were instructed to ignore the peripheral words (identified by ink color and location). Good readers made *more* errors of intrusion than poor readers implying that, despite instructions, good readers picked up more information from the visual periphery than did poor readers. Whether the poorer reader's view was actually constricted might have been ascertained by eye records indicating more fixations of shorter extent.

The technology of the on-line computer system used by McConkie and Rayner enabled them to present portions of text (in standard or altered form) as a function of eye movements, while simultaneously recording the reader's eye activity. Though they only tested a few skilled readers, their techniques could be adapted for investigations about the developing skill of reading. It may be the case that the poorer or beginning reader does not utilize the variety of information available to him within a single fixation. By varying both the location and the type of information potentially available to such a reader, a more accurate description of his information processing activities may be obtained. When letter or homophone changes are made in the text, the reader who relies more heavily on semantic and syntactic cues would evidence less disruption of his average eye activity than the one who is still struggling with decoding stages in reading. By making the technology more amenable for work with children,[5] researchers may also probe the possible relation between development and reading skill. A recurrent theme in developmental research is the child's difficulty in handling multiple inputs. Haith (1971) has hypothesized that children have difficulty in sequentially transforming simultaneous input into a more permanent storage form. Different types of information which bombard the reader in a single fixation may be recognized by the child but he may be unable to organize the different inputs into a sequential form or integrate them in such a way that helps him both direct his next fixation and interpret the meaning of the inputs. With development and experience may come some automaticity in organizing the diversity of inputs from the visual field, which provides the child with more time to operate on higher-order problems in reading (LaBerge & Samuels, 1974). Because of his difficulty in reducing multiple inputs to a more manageable form, a child may only attend to the salient information which is most likely to be within his foveal area (Mackworth & Morandi's "tunnel vision" effect, 1967). The child would, therefore, gain less information about specific letters, word-shape, and word length from the periphery, resulting in subsequent saccadic movements being smaller. Since the child is probably less experienced in utilizing semantic and syntactic cues inherent in printed language to gain meaning, his average fixation duration—the time for

processing input—would probably be lengthened. The behavioral predictions from this analysis have been found: children generally have more short saccadic movements and more fixations of longer duration do adults (Mackworth & Bruner, 1970). However, to assert that the underlying reasons for these particular patterns of eye activity are as hypothesized above requires testing by means of clever manipulation of independent variables related to stimulus materials.

Thus, there are several basic questions as yet unanswered about information usage within a single fixation. Though there have been unreliable data that peripheral acuity increases with age (Lakowski & Aspinall, 1969; Holmes, 1970), our research has indicated that, even when processing demands increase, there are no age differences in peripheral visual acuity (Cohen & Haith, 1977). The processing demands in reading are so complex that it is necessary to investigate both the component skills called into action during a single fixation and the dynamic aspects of reading occurring over multiple fixations.

Guidance of Subsequent Fixations

The variety of control models of eye activity were presented in the first section of this chapter. From both an empirical and a logical perspective, models which incorporate both local (stimulus) and internal control over eye movements seem most plausible. This position has most recently been represented by Hochberg (1970) and McConkie (1974). The chief difference between the two positions is that the former stresses an hypothesis-testing model (akin to Goodman, 1970), while the latter emphasizes an information-seeking model. Both positions allow for utilization of multiple inputs before a decision to refixate is made. These inputs include not only physical characteristics of the visual stimulus but, also, the reader's awareness of syntactic and semantic cues, familiarity with the material or subject matter, and processing of information from the previous fixation. Superimposed upon this massive amount of information is the temporal and spatial information about where the eye is and has been—an important consideration in light of the frequency of accurate regressive eye movements to areas of difficulty (Kolers, 1974).

Because the locus of fixations can be so variable and because these are multiple inputs into the decision for refixation, future researchers should try to establish whether the component bits of information are acquired and utilized in any hierarchical fashion for the beginning reader and if this same hierarchy of information holds for the skilled reader. Experiments which present contradictory cues to the reader or information contrary to his linguistic expectations (Wanat, 1972) should help tease apart how a reader integrates so much information in so short a time period (a quarter-of-a-second) in order to redirect his eyes and prepare for the next deluge of input.

Extraction of Meaning from Visual Input

This is the question with which we began: how do we arrive at meaning from a visual display? Virtually every researcher who has pursued the study of eye movements in reading or pictorial scanning has reiterated the fact that the eyes merely reflect what the brain is doing and the brain's task is to derive meaning from stimulation. In accordance with this position, researchers need to focus on experiments which examine eye activity in response to manipulations of semantic information inherent in reading materials. Initial forays in this area were conducted by Mehler, Bever, and Carey (1967); Wanat (1972); and McConkie and Rayner (1973), though these investigators placed more emphasis on syntactic structure in text than on semantics. Changes in number of forward and regressive fixations and fixation duration were noted as responses to their linguistic manipulations.

Sentence comprehension, however, requires more than the combination of word meanings alone. Word meanings must be integrated with the structural meaning of the sentence. "The meaning of each word interacts with the structural meaning of the sentence to yield the meaning of the sentence. The *structural meaning* of a sentence is the syntactic form of the sentence [e.g., deep structure] abstracted from the particular words in that sentence" (Glucksberg & Danks, 1975: 78). An accomplished reader continually organizes phrases and sentences into meaning units. While the "unit of perception" for the beginning reader (a recurrent topic of debate) may be tied to physical characteristics of the input, the "unit" for the

skilled reader more likely represents a semantic component. Hence, the mature reader is constantly engaged in interrelating meaning units to understand a passage. This integration implies a necessary transportation of meaning over a considerable number of fixations. When a sentence is either lexically or syntactically ambiguous, one would expect an interrupt flag to be raised to alert the reader to the resultant semantic difficulty. The reader's response is likely to be characterized by an initial increase in fixation duration and/or regressive eye fixations to areas which may help him disambiguate the sentence.[6] Note that these expected variations in eye activity are similar to those found with simple syntactic manipulations (Wanat, 1972), though these independent variables—semantically-related manipulations of prose—presumably require higher-order processing than do simple syntactic manipulations. The robustness of these parameters of eye activity as dependent variables can also be utilized to address developmental questions about the appreciation of semantic confusions in text.

Just as Cooper (1974) demonstrated a means of using eye activity to reflect comprehension of oral language, so the same behavior could be monitored to infer comprehension of semantic structures in text. Integration of meaning over a range of sampled information implies that the reader is engaged in a constructive process. Bransford and Franks (1971) have demonstrated that listeners organize sentences they hear into a single schema which is more efficient for information storage. When printed information is systematically varied with respect to the content familiarity and linguistic expectancies of the reader, the subsequent eye sampling behavior of the reader should give us some insight into the constructive processes he uses to organize the visual input meaningfully and efficiently.

Conclusion

The eyes play an inextricable role in the process of normal silent reading in that they serve as sensory receptors through which printed information is transmitted to the brain. In this chapter, the author has presented the primary data on eye activity and reading as well as some directions for future

research directed toward unraveling the processes involved in gaining meaning from print.

Though no particular model of the reading process has been promoted in this chapter, a word is in order about the ability to translate visual symbols into meaning. The argument has frequently been made, particularly by linguists (e.g., Conrad, 1972), that visual symbols are translated into their acoustic equivalents or phonological form before meaning is attained. Two lines of evidence seem to lend support, albeit inconclusive, for this position. First, most children acquire speech and language functions prior to their ability to read. In doing so, they learn to abstract meaning from auditory information. By mapping the skills acquired from this learning onto visual symbols, the child finds another way of deriving meaning from symbolic materials. While the link-up of visual symbol to phonetic coding may be necessary or preferred in learning to read, this does not necessarily imply that the skilled reader must continue to translate visual input into auditory form before comprehension is possible. Second, much evidence has been accumulated to demonstrate subvocalizing activity during reading, even in the mature reader (McGuigan, 1970). While this process may accompany visual information processing, it does not follow that auditory coding is necessary for comprehension of visual symbols.

In pursuance of this argument, the author conducted an informal experiment in which members of the university community were first asked whether they thought auditory recoding of visual input was a necessary part of their deriving meaning from printed material. Most respondents replied affirmatively. They were then asked to read silently the following sentence attributed to Jay Samuels: "the buoy and the none tolled hymn they had scene and herd a pear of bear feet in the haul" (LaBerge, 1972: 245). Almost every person reported stumbling over the words, restarting the sentence, or giving up. Yet when the sentence was read to them, they had no trouble understanding it. As LaBerge notes:

> If visual words were coded into word sounds before they made contact with linguistic comprehension levels, then there should be no disruptive effect due to the spelling variations of the sentence, so long as familiarity of the visual words is controlled... the code in which visual written material even-

tually is cast enroute to the comprehension processes need not be exclusively auditory *or* exclusively visual for a given individual reader. It is conceivable that both the auditory and vial codes may make contact with comprehension processes, and that during reading they may make this contact in parallel, or one at a time by fluctuating in some fashion between the two modalities (pp. 245, 242).

To summarize, there are three major reasons for utilizing eye activity as a dependent variable in the study of the reading process:

1. Eye activity is a directly observable component of the reading process.
2. Eye activity is fast and variable enough to map the rapid acquisition of meaning from print.
3. Eye activity reflects the complex, higher-order functioning of the nervous system in the same time frame in which these central processes are operative.

Eye activity, then, represents a window through which the translation of printed information into meaning can be studied.

Footnotes

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2. The author, a graduate student at the Lab of Human Development, Harvard University, was supported by NIMH predoctoral fellowship 1-F01-MH 58205-01. Her current address is the Developmental Psychology Department, University of Denver, Denver, Colorado 80210.
3. See Huey (1908) for a review and bibliography of late 19th century research on eye movements and reading.
4. A report of a Conference on Visual Information Processing and Technology, directed by Sam Gibson and sponsored by the Essential Skills Program of National Institute of Education, expanded upon many of the ideas presented here.
5. An on-line computer system with a hardware interface which tracks eye and head position has been developed in our laboratories at the University of Denver for work with preschool children.
6. Collaborative research is in progress with Dr. Joe Danks to address such questions.

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Efficient Processing Activities in Reading

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Reading is a composite of many subskills and therefore requires the coordination of numerous component processes. Proficient readers find reading a relatively easy activity. They are able to process written information smoothly and rapidly, with little or no conscious awareness of the mental activities that take place while they read. In other words, proficient readers carry out many of reading's component processes automatically and efficiently. As long as the written information is not too abstruse, this efficiency facilitates comprehension because these readers can concentrate their mental efforts on the meaning of the material.

In contrast, nonproficient readers frequently find reading a difficult activity. These individuals cannot process written material smoothly and rapidly; they must expend considerable mental effort in the execution of individual component processes. As a result, the comprehension of even relatively simple text may be beyond the reach of nonproficient readers. The proportion of their mental faculties that must be directed to decoding activities is so large that the meaning of the written material is ignored to a considerable extent. Although nonproficient readers may be able to carry out some of reading's component processes, their executions of these processes are inefficient. This inefficiency may result in a deterioration in the functioning of the process when it is exercised concurrently with other processes. Thus, the performance of a component process interferes with the concurrent performances of other component processes more for beginning readers than for skilled readers.

Psychologists long ago recognized that with practice the execution of a skill tended to become easier, more efficient, and in need of less conscious effort (James, 1890; Lashley, 1951; Woodworth, 1938). Indeed, Huey (1908), a pioneering reading

researcher and psychologist, made precisely this point when he stated that "To perceive an entire new word or other combination of strokes requires considerable time, close attention, and is likely to be imperfectly done....[Practice, however,] progressively frees the mind from attention to details, and makes facile the total act, shortens the time, and reduces the extent to which consciousness must concern itself with the process" (p. 104).

One approach frequently used to study the acquisition of reading skills is to examine the repertoire of subskills possessed by individuals of different reading abilities. However, readers differ, not only in the particular subskills they possess, but also in the extent to which they are able to exercise their subskills efficiently.

In this paper, the acquisition of reading skills is explored by concentrating on various ways of conceptualizing and empirically elaborating processing efficiency per se. In pursuit of this goal, a general discussion of the notion of processing efficiency is first presented. Next, a model that deals explicitly with automatic information processing in reading (LaBerge & Samuels, 1974) is reviewed. Following this review, there is a methodologically oriented discussion of relevant research. Finally, additional procedures for studying the efficiency of reading skills are discussed.

Capacity Limitations and Processing Efficiency

Data- and Resource-Limited Processing Activities

NORMAN AND BOBROW'S MODEL

An information processing model that is relevant to our discussion of processing efficiency was presented by Norman and Bobrow (1975), who argued that the performance of a process can vary with both the nature of the input data and the amount of processing resources allocated to the process. Information processing systems possess a limited amount of processing resources (memory, processing effort, communication channels). As a result, different processes may have to compete for and share portions of these limited resources. So long as the amount of resources that processes jointly require does not exceed the total amount available, the operation of one

process does not interfere with that of another. However, if the joint requirements of processes exceeds the amount of resources available, selective resource allocation must take place. When this occurs, the performance of at least one of these processes will deteriorate.

The allocation of additional processing resources to a task often results in improved performance on the task. Whenever performance on a task can be improved by an increase in the amount of processing resources, the performance is considered to be "resource-limited." However, if additional resources continue to be allocated to the task, a point may be reached where such increases have no additional influence on performance. In other words, a point may be reached where all the processing that can be done has been done. In this case, all variation in performance on this task now depends solely on the nature of the data received. Whenever this point is reached, performance on the task is considered to be "data-limited."

On most tasks, performance can be considered either resource- or data-limited depending on whether or not the allocation of additional processing resources has an influence on performance (Norman & Bobrow, 1975). While allocating additional resources to a task that is data-limited does not alter performance, changing the nature of the data presented can alter performance. Additionally, the imposition of conditions that place increased demands upon a system's limited processing resources can result in performance on a task shifting from data limitations to resource limitations, because the increased demands can result in insufficient resources remaining available for maximum performance. Such a shift is most likely for those data-limited tasks for which maximum performance initially required a large portion of the available processing resources. Tasks for which data-limited performance requires only a small portion of the processing resources would be less likely to undergo this shift. Presumably, the processes involved in the performance on these latter tasks are highly efficient, requiring only a small allocation of processing resources.

READING EFFICIENCY AND NORMAN AND BOBROW'S MODEL

A considerable amount of conscious effort is often required to perform an unfamiliar task. However, when the

task is repeatedly practiced, performance becomes increasingly automatic, and less conscious effort is required. Thus practice can result in increased processing efficiency, that is, increased performance with no extra allocation of resources. Reading processes can be characterized as being efficient for skilled readers and inefficient for beginning readers. In terms of Norman and Bobrow's model, these characterizations mean that processes are less likely to be resource limited for skilled readers than for beginning readers.

Thus the demands which component reading processes make on processing resources are not likely to exceed the total amount of resources available when the reader is proficient. For good readers, the lower-order processes involved in decoding a written message do not normally interfere with the concurrent performance of the higher-order processes involved in semantic comprehension, even when these two levels of processes share the same limited resources. However, these lower-order and higher-order processes may often interfere with each other in unskilled readers. The inefficiency of these readers' processes increases the probability that the total amount of available resources will be exceeded.

When a written passage is relatively easy to comprehend, the amount of limited processing resources that must be allocated to higher-order processes is presumably small. A relatively large surplus of resources is then available for allocation to lower-order processes. Thus for easily comprehended passages, the total amount of available resources is likely to be sufficient to allow both skilled and less skilled readers to read the passage. In contrast, when a written passage is relatively difficult to comprehend, a large amount of processing resources must be allocated to higher-order processes. In this case the remaining amount of resources available for allocation to lower-order processes is small. Since lower-order processes are efficient for skilled readers, the small amount of remaining resources is likely to be sufficient for these readers to read the passage. However, this same small amount of remaining resources may not be sufficient for the inefficient low-level processes of less skilled readers. As a result, these readers may not be able to read this difficult passage. If an extremely difficult written passage is encountered, the resource demands of the higher-order processes may be extremely high. In this case the lower-order processes of even skilled readers

may receive an insufficient allocation of resources. Therefore, the reading of the proficient reader may be halting and slow for difficult passages.

The Concept of Attention

The information processing model proposed by Norman and Bobrow is very general and does not require the identification of the specific sets of factors that constitute limited processing resources. Undoubtedly there are numerous factors that set limits to human information processing capacity (cf. West, 1975). Perhaps no concept has been more frequently associated with capacity limitation than attention. Because the remaining discussion of processing efficiency makes frequent use of this concept of attention, a brief consideration of this notion is in order. William James (1890) described attention in *The Principles of Psychology* in the following manner:

> Everyone knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what seems several simultaneously possible objects or trains of thought.... It implies withdrawal from some things in order to deal effectively with others (p. 403).

At a later point in the book, James elaborated the notion of attention as follows:

> How many ideas or things can we attend to at once.... Not easily more than one, unless the processes are very habitual.... Where however, the processes are less automatic...there must be a rapid oscillation of the mind from one to the next, and no consequent gain in time (p. 407).

Thus James identified the properties of selectivity and capacity limitations as important characteristics of attention. With respect to the property of capacity limitation, he noted that we are able to process only one thing at a time, except when the processes involved have been so well learned that they can be carried out automatically. James also suggested that processes that are not automatic may appear to be carried out simultaneously when the focus of attention rapidly oscillates from one activity to another. In terms of Norman and Bobrow's model, this rapid oscillation of attention is analo-

gous to sharing this limited processing resource. Presumably if attention is not focused for a sufficient duration on a nonautomated activity, performance on this activity will be poor.

The Mechanisms of Processing Efficiency

When the total amount of resources (e.g., attention) required by reading processes exceeds the total amount available, performance is likely to deteriorate. Since the amount of resources that must be allocated to a particular process is generally greater for the beginning reader than for the skilled reader, the component processes of the beginning reader are more likely to make demands on resources that exceed their availability. Assuming that the total amount of resources normally cannot be increased, the beginning reader must learn to carry out various processing activities with less consumption of resources.

Information processing efficiency is presumably acquired largely as a result of practice. What are the changes in the reader's processes that allow more efficient processing of written messages? To the extent that insufficient attentional resources are a cause of poor reading performance, the particular changes in the processes, and the forms of perceptual learning that result in lowered demands for attentional resources, must be identified.

At least two types of changes in processing activities can reduce the demands for attentional resources. First, the amount of information that is actually allocated to resources can be reduced. A written passage contains far more information than the reader can attend to at one time. Much of this information is either irrelevant to the meaning of the passage or redundant with other information contained in the passage. Therefore, the efficiency with which attentional (or other) resources are used can be increased by selectively allocating these resources to only those aspects of the written message that are most relevant for comprehension. In this case, economy in the use of attentional resources is achieved by avoiding the consumption of these resources on redundant and irrelevant information. A number of more detailed discussions of the role of selectivity in reading are available elsewhere

(Gibson, 1969; Gibson & Levin, 1975; E. Smith & Spoehr, 1974; F. Smith, 1971).

A second type of change in processing activities that can reduce demands for attentional resources occurs when processes have been so thoroughly practiced and learned that they can take place even when they are allocated minimal resources. In this case, the same amount of information receives processing for both efficient and less efficient readers. However, the processes of the efficient readers require a smaller amount of attentional resources, because they are carried out automatically. This automatic source of processing efficiency is investigated in detail in the remaining sections of this paper. In passing, it should be noted that there is no reason why the two general sources of processing efficiency cannot be involved in the same reader.

Automatic Information Processing in Reading

LaBerge and Samuels' Reading Model

AN OVERVIEW

LaBerge and Samuels (1974) recently presented an information processing model that deals explicitly with the acquisition of automated processing skills in reading. These authors argue that before the information in written material can be comprehended, it must undergo processing in a series of component processing stages involving internal representations, or codes, stored in visual, phonological, episodic, and semantic memory systems. Each level in this processing system need not be involved in all acts of processing written material, for there are several alternative routes that information may take as it is transformed through various stages. However, the general flow of information in this model is hierarchically organized, with the initiation of higher-level processes contingent upon adequate informational input supplied by lower-level processes. In this respect, LaBerge and Samuels' model is similar to other pattern recognition schemes (Lindsay & Norman, 1972; Selfridge & Neisser, 1960).

The skill with which processing takes place at each level in the processing hierarchy is assumed to be acquired through an associative learning process. During early stages of the

development of skills, the codes at any given level in the processing system can be activated only with assistance from a limited capacity attentional mechanism. Later, after the processing skill has become well learned, attentional assistance is no longer requisite and codes can be activated solely on the basis of input stimulation. The degree of skill acquisition can be evaluated with respect to both the accuracy with which processing takes place with attentional assistance and the extent to which processing is able to progress automatically, or without use of attentional resources. LaBerge and Samuels consider a skill to be automatic when "it can complete its processing while attention is directed elsewhere" (LaBerge & Samuels, 1974: 295).

The view that familiar material may be processed into internal codes without use of attentional resources is consistent with a number of other attentional models (Deutsch & Deutsch, 1963; Norman, 1968). LaBerge and Samuels emphasize that the attentional mechanism retains the ability to selectively activate codes even after automation has been achieved.

INFORMATION PROCESSING IN THE VISUAL MEMORY SYSTEM

In the first stage of LaBerge and Samuels' model, written information is transformed through a hierarchically organized series of codes in the long term visual memory system. At the bottom of this hierarchy are feature detectors which analyze the various lines, angles, and curves that make up written text. Through a perceptual learning process that is likened to the first stage in concept learning (Trabasso & Bower, 1968; Zeaman & House, 1963), the reader learns which subsets of features are relevant for making discriminations between letters. Once appropriate features have been identified, the learner can begin the construction of letter codes with the aid of attention, by rapidly scanning each letter's constituent features. However, "every time the subject organized the features into a particular letter code, some trace of this organization between features and letter code is laid down" (LaBerge & Samuels, 1974: 299). Eventually, the association between the new letter code and its corresponding features becomes strong, and attentional resources are no

longer required for letter-code activation. At this point, features can be processed into the letter code automatically.

The activation of letter codes results in a flow of information through the visual memory coding hierarchy to spelling-pattern codes, which in turn feed into visual-word and, possibly, even visual-word-group codes. As was the case for letter codes, these higher-level codes are constructed with the aid of attention and initially can be activated only with attentional assistance. With repeated activation, the associations between these higher-level codes and their corresponding subordinate codes gradually become so strong that the activation of subordinate codes can result in the activation of the higher-level codes without attention. While the flow of information through the visual memory system is from lower-level to higher-level codes, each level within the system need not always be involved. For example, LaBerge and Samuels suggest that features might directly activate spelling-pattern or word codes without the intervening activation of letter codes (E. Smith & Spoehr, 1974; F. Smith, 1971).

INFORMATION PROCESSING AND THE VISUAL, PHONOLOGICAL, AND SEMANTIC MEMORY SYSTEMS

After information has been processed in the visual memory system, codes in the phonological memory system are activated. These codes feed into codes in the semantic memory system. LaBerge and Samuels suggest that spelling-pattern, word, and word-group codes are activated in the phonological system, while word-meaning and word-group-meaning codes are activated in the semantic system. Attention is required during the code construction and the initial stages of skill acquisition. However, some connections between phonological-word and semantic-word codes may be fairly automatic by the time reading instruction commences, as most children become well-practiced oral language users at a young age. The flow of information between memory systems at very early stages in code acquisition may be mediated by a memory for contextual events. LaBerge and Samuels liken this memory to Tulving's "episodic" memory (1972).

Just as the flow of information through the visual memory system has alternative routes, the flow of information

through the phonological and semantic memory systems also may follow alternative routes. When the entire processing system is considered, the number of possible alternative routes is quite large. Indeed, most of the inward-flowing processing routes postulated in reading by researchers can be encompassed by one or another of these alternative paths. For example, a visual-word code may activate a phonological-word code, which in turn may activate a word-meaning code. Alternatively, a visual-word code may directly activate a corresponding semantic-meaning code without any phonological code involvement (Bower, 1970; Goodman, 1972; Kolers, 1970; F. Smith, 1971). LaBerge and Samuels point out that our quick recognition of homonyms such as "two" and "too" lend credence to this latter option.

The particular selection of codes and routes postulated by LaBerge and Samuels are not essential to their general reading model. However, the role attention plays in the initial code construction, and attention's slowly increasing expendability with skill development, are critical.

Comprehension takes place in LaBerge and Samuels' model when the reader organizes word-meaning and word-group-meaning codes in the semantic system by rapidly shifting his attention among these meaning codes. This rapid shifting is made difficult when attention must allocate a large portion of its limited resources to nonsemantic levels of processing. Thus a goal of fluent reading is to automate most of the processing at levels below the semantic level, so that attentional resources can be allocated largely to processing in the semantic system.

Discussion of LaBerge and Samuels' Reading Model

HIGHER-ORDER LINGUISTIC PROCESSES AND READING

The reading model proposed by LaBerge and Samuels (1974) cannot be considered comprehensive because the roles played by higher-level linguistic processes have received little elaboration. With the stipulation that the mental activities that take place at low levels in the processing system function relatively independently of higher-level activities, there are few reasons why this particular model cannot be highly useful.

However, to the extent that the fundamental nature of lower-level processing activities is modified by the functioning of higher-level processing activities, allowance must be made for the influence which higher levels have on lower-level functioning.

The general flow of information through LaBerge and Samuels' reading model is from lower-level to higher-level processing stages. No provision is made in the model for the reverse flow of information. That is, there is no specified mechanism by which information at a higher stage can influence some of the processing activities in a lower stage. In this respect, the model can be contrasted with other models that emphasize the interactions between component processes (Goodman, 1972; Mackworth, 1972).

There are a number of factors which suggest that the activities of higher-level processing components exert an influence on the activities of lower-level processing components. The rapidity with which information must be interpreted by low-level processes makes it likely that input data are at times erroneously encoded. Consider the influence which an error in encoding material at a low level would have on the activities of higher-level components, if the sole source of information for processing at the higher level was the erroneously encoded information received from below. Presumably, there are mechanisms which monitor and correct the accuracy of information received from below. Such mechanisms, which are assumed to involve relatively high-level processing components, make extensive use of contextual constraints and the redundant nature of the information contained in a written message.

"Pandemonium," a pattern recognition scheme proposed by Selfridge and Neisser (1960), provides for the elimination of low-level errors in a manner that could probably be incorporated into LaBerge and Samuels' model. The pandemonium scheme consists of a hierarchical arrangement of devices (not unlike the codes described by LaBerge and Samuels) that are activated when the presence of a particular pattern of encoded information is detected in a number of lower-level devices. When one of these detection devices is activated, it emits signals which feed into corresponding higher-level devices. The strength of these signals varies as a

function of the number and/or intensity of relevant signals received from lower-level devices. Since the extent to which the higher-level devices are activated depends upon the combined intensity of signals received from numerous lower-level devices, the impact of any given erroneous signal from a low-level device tends to be progressively diluted as information undergoes continually higher levels of processing. In other words, high-level processing components make use of information that has been gleaned from several redundant sources of information.

A number of processing schemes have been devised which assign a far more active role to high-level linguistic processing components (Cooper, 1972; Halle & Stevens, 1962; Neisser, 1967). Often referred to as analysis-by-synthesis models, these schemes propose that language analysis proceeds in a manner that is similar to Bruner's "hypothesis testing." For example, Halle and Stevens suggested that the analysis of speech proceeds by matching an internally recreated version of the sensory signal with the actual stored input. A hypothesized version is accepted as true when it closely matches the stored input. The low-level processing components in such schemes must initially analyze only the amount of information needed to generate reasonable hypotheses. Unlike the pandemonium scheme, the analysis-by-synthesis schemes reflect a view that is not consonant with LaBerge and Samuels' model.

Study of the types of errors readers make lends credence to the view that higher-level linguistic processes are actively involved in some fairly low-level processing activities. For example, Goodman (1969, 1970, 1972) has observed that oral reading errors, or miscues often can be predicted more accurately from higher-level factors (e.g., contextual relevance) than from lower-level factors (e.g., spelling anomalies). Kolers (1970) reported that an analysis of errors made by subjects reading distorted texts suggests that these readers were quite sensitive to syntactic constraints. The word substitution errors which occurred were likely to have been syntactically acceptable with the preceding text. Indeed, syntactic sensitivity is apparent even in the reading errors of young children (Weber, 1970). In each of these cases, the reader appears to make use of his linguistic knowledge in an attempt to make sense of written material. Perhaps low-level visual processing activities are executed less carefully when contextual constraints have made a particular meaning rela-

tively certain. Elaboration of LaBerge and Samuels' model is needed before it can adequately account for reading errors whose presence is attributable to higher-level processes.

THE HEURISTIC VALUE OF READING MODELS

The fact that LaBerge and Samuels' model cannot account for the influence which high-level linguistic processes have on reading does not necessarily mitigate the usefulness of this model. Comprehensive reading models, which attempt to make a relatively complete description of the reading process, are generally unable to generate specific hypotheses that can be subjected to empirical verification. Indeed, the dismal performance of comprehensive models in this respect led Calfee (1974) to refer to such models as "Jello" models (see Marsh, this volume). In contrast to the more comprehensive reading models are models which attempt to elaborate a more restricted set of phenomena. While these partial models fail to account for the complexities of reading processes, they can serve the valuable heuristic role of generating hypotheses that are specific enough to be empirically investigated. The final assessment of LaBerge and Samuels' model will largely depend on its ability to play this heuristic role, by generating experimentally verifiable predictions about the automatic performance of particular component processes.

Research on Processing Efficiency in Reading

Methodological Considerations

As was demonstrated earlier in this paper, the notion that the cognitive processes involved in reading become automated with practice has a long history in psychology. LaBerge and Samuels' model of reading adds to the earlier notions on how processes become automated. They argue that when a process is practiced, associative learning takes place that decreases the amount of attentional resources required for the process to function.

CONVERGING OPERATIONS

Research efforts directed toward elucidating mental processes must deal with a question that is familiar to

cognitive psychologists. Can valid inferences be made about the characteristics of processes that are not directly observable? In an affirmative answer to this question, Garner, Hake, and Eriksen (1956) suggested that the properties of mental events may be delimited by experimental designs that employ converging operations, which they define as follows:

> Converging operations are any set of experimental operations which eliminate alternative hypotheses and which can lead to a concept which is not uniquely identified with any one of the original operations, but is defined by the results of all operations performed (p. 158).

THE SUBTRACTION METHOD

The Subtraction Method, first used by Donders over one hundred years ago, is one set of converging operations which has become very popular in the past fifteen years. Recent studies have employed a version of the Subtraction Method in an attempt to measure the extent to which automatic processing takes place under a variety of experimental conditions (LaBerge, 1973a; LaBerge & Samuels, 1973). Although the mental processes of interest in cognitive research cannot be directly observed, they are assumed to take place in real time. For this reason, the duration that a process takes to complete its processing has become one of the most frequently used dependent variables in psychology. Reaction time, normally measured from the onset of the stimulus presentation to the elicitation of the subject's response, is assumed to represent the minimum duration required by the subject to correctly respond to a stimulus (Pachella, 1974).

One of the goals of cognitive research is to be able to attribute the effects of particular experimental manipulations to a mental operation that intervenes between the stimulus and the response. Because the reaction time interval is filled with more than one process, a procedure is needed for isolating an intervening process and measuring its duration. The Subtraction Method is a set of converging operations that provides a procedure for doing this.

The Subtraction Method "is applicable when the performance of an experimental task involves the sequential action of a series of mental events" (Pachella, 1974: 46). To measure the duration of an isolated process the reaction time of

an experimental task that contains the process of interest is compared to the reaction time of a comparison task that is identical to the experimental task, except for the deletion of the process of interest. The difference between the two reaction times is assumed to represent the length of time required to execute the deleted process.

To study the effects that certain experimental manipulations have on the length of time required to carry out a particular mental process (i.e., the isolated process), the difference between the reaction times obtained under the experimental- and comparison-task conditions are compared as a function of the experimental manipulations (Pachella, 1974). When experimental manipulations do not affect a particular process, the duration of this process, as measured by the above procedure, should not be influenced by the experimental manipulations. In this case, differences in reaction times obtained as a function of the experimental manipulations must be attributed to changes in the durations of one or more of the other intervening processes.

Automatic Perceptual Processing

LaBerge and Samuels (1974) account for increased reading efficiency in terms of the gradual automation of processes. At the lowest level in their model, visual information is analyzed by feature detectors. The outputs of these feature detectors activate letter codes stored in visual memory. While proficiency in attentively processing features into letter codes is rapidly achieved, proficiency in automatically carrying out these same activities is acquired only gradually.

For this reason individuals may be able to identify unfamiliar letters as rapidly as familiar letters when their attention is focused on the letters. However, they may not be able to identify the unfamiliar letters as rapidly as the familiar letters when the letters are encountered while their attention is focused elsewhere. Although both types of letters can be processed with assistance from attention, only the processing of the familiar letters can take place without assistance from attention (automatically). The processing of the unfamiliar letters can begin only after attention has had time to switch its focus to these letters. Thus, if the unfamiliar letters are

encountered at a time when they are not expected, they may be processed more slowly than the familiar letters by the duration required for attention to switch its focus to the letters. Such attention switching has been estimated to require as long as 80 msec. (LaBerge, 1973b).

A STUDY OF AUTOMATIC LETTER RECOGNITION

LaBerge (1973a) examined three predictions based on the above argument. First, he predicted that recognition time would be greater for unfamiliar letters than for familiar letters when the letters were encountered under conditions of nonattention (i.e., conditions where attention switching was required). Second, he predicted that the differences between the recognition times found under conditions of nonattention would gradually decrease as practice was obtained on the unfamiliar letters. Third, he predicted that the recognition times for two types of letters would not differ when the letters were presented under conditions of attention. This latter prediction was based on the assumption that any difference in response times under conditions of nonattention would be due to the fact that only the familiar letters could be processed automatically (i.e., while attention was switching to the task).

The measurement of letter recognition latencies. LaBerge used letter-matching latencies to assess relative letter-recognition speeds. Although these latencies contain time-consuming activities in addition to those involved with letter recognition, the differences between these latencies provide useful estimates of relative recognition speeds (cf. Posner, Lewis, and Conrad, 1972). The subjects in this study were presented both familiar and unfamiliar letters. The familiar letters were the letters *b d p q*. Presumably these letters were at an asymptote of familiarity and could be processed both with and without assistance from attention. The unfamiliar letters were the arrow-like shapes ⊢⊣ ⊢⊣. Presumably these letters could be processed only with the aid of attention. In other words, the unfamiliar letters could be processed under conditions of nonattention only after an attentional switch was made.

The momentary control of attention's focus. To obtain letter-matching latencies for the familiar and unfamiliar letters under conditions of nonattention, a cueing technique (LaBerge, Van Gelder, & Yellott, 1970) was used to induce the

subject to focus his attention momentarily on a particular letter. A single letter was briefly presented at the beginning of each trial. This letter served as a cue which informed the subject that a single target letter identical to the cue was likely to appear after a short interval. When the target letter was identical to the cue, the subject was to press a button as rapidly as possible. When this target letter did not match the cue, the subject was to do nothing. Since the proportion of positive responses on this successive matching task was always greater than 50 percent, the presentation of the cue was assumed to create a strong expectation that the target would be identical to the cue. This expectation presumably resulted in the subject's focussing his attention on the expected letter.

On occasional trials the presentation of the cue was followed, not by a single letter, but by an unexpected pair of letters that had been selected from the set of familiar and unfamiliar letters described above. The subject was instructed to press the button if the pair of letters matched and to do nothing if they did not match.

The trials with the unexpected pairs of letters provided the data on letter recognition under conditions of nonattention (the nonattention task). On the first day of testing, the results from these simultaneous-letter matching trials indicated that the unfamiliar-letter pairs took 48 msec. longer to respond to than the familiar-letter pairs. The size of this difference decreased as the subjects practiced on the matching task. Indeed, by the fourth day of practice the letter matching latencies for the two types of letters were indistinguishable.

By themselves, these findings do not strongly support the idea that the familiar letters were processed more automatically than the unfamiliar letters. Any one of a number of processes may have been responsible for the differing response times. For example, it is possible that the response latencies were shorter for the familiar letters simply because they underwent more rapid attentive processing.

Application of the Subtraction Method. The Subtraction Method was employed to demonstrate that the differences between the two letter-matching latencies was due to differences in automatic perceptual processing. A separate group of subjects was tested on a comparison task. For the comparison task, the familiar and unfamiliar letters were used

as both cues and single-letter targets in a successive-letter matching task. This procedure allowed letter-matching latencies to be gathered for the two types of letters under conditions when they were expected (the attention task). The resulting latencies were assumed to involve all of the processes involved in the nonattention task except for those processes that functioned automatically (i.e., before attention had time to switch its focus to the target letters). No significant differences (9 msec.) were found between the familiar and unfamiliar letter-matching latencies in the attention task, and LaBerge concluded that the inequalities found in the nonattention task were due to differences in automatic perceptual processing.

Conclusions and implications. The recognition time for familiar letters was shorter than that for unfamiliar letters in the nonattention task, but not in the attention task. Therefore, the familiar letters appeared able to undergo more automatic processing than the unfamiliar letters. However, the difference between these two types of letters vanished when the unfamiliar letters were sufficiently practiced to be themselves automatically processed.

These results are consistent with LaBerge and Samuels' reading model (1974) and the predictions discussed above. Unlike many reading models (see Marsh, this volume), LaBerge and Samuels' model would seem to serve a heuristic purpose. It can be used to generate hypotheses that are relatively specific and testable. In addition, the findings support the view that perceptual learning continues well after a high level of performance is achieved in an attention condition. This view has pedagogical significance, for it implies that proficiency in recognizing letters encountered at moments when attention is focused upon the letter-recognition activity does not guarantee comparable proficiency in a situation where attention is not continually focused upon the letter-recognition activity. The fact that a beginning reader may be able to identify the unfamiliar letters of the alphabet rapidly does not necessarily mean that he will be able to carry out this processing concurrently with the other processes involved in reading.

Children who frequently make letter reversal errors when reading have been found to make few such errors when letters are individually presented (Liberman, Shankweiler,

Orlando, Harris, & Berti, 1971). Perhaps the attentional requirements of reading are such that only a small amount of attention can be allocated to the process of letter identification. Therefore, frequent letter reversal errors may indicate that a child's proficiency in letter recognition is not yet sufficient to allow accurate automatic processing.

In assessing a child's letter-identification skills, it may be important to take into account the effort that goes into letter recognition. For if the recognition can be carried out only by consuming large amounts of limited attentional resources, the child may be unable to allocate sufficient processing resources to other vital processes. Perhaps the procedures used in LaBerge's study will prove useful in assessing the efficiency of reading skills in problem readers.

CRITICISM OF THE LABERGE STUDY

Applicability of the Subtraction Method. There are a number of criticisms that can be made of LaBerge's study (1973a). The most fundamental of these criticisms questions the conclusion that the difference between the recognition latencies obtained for familiar and unfamiliar letters on the experimental task is due to an automatic stage of processing. Since letter recognition involves numerous processing stages, the Subtraction Method was used to isolate the automatic stage of processing (i.e., the stage that preceded attention's focussing on the target letter in the nonattention task). Thus, the validity of the main conclusions drawn in this study depends on the applicability of the Subtraction Method. However, this method is applicable only when a number of assumptions (Pachella, 1974) are made. Unfortunately, some of these assumptions can be made only on tenuous grounds.

To begin with, it must be assumed that performance on the letter-matching tasks reflects the activities of a series of discrete mental processes. The various component processes that influence the response latencies must function independently of one another. For example, the processes involved in the execution of the button-pressing response cannot affect the manner in which information is processed by other component processes. No evidence was presented concerning this assumption. Sternberg's Additive Factor Method (1969) might provide

means of testing assumptions about the discreteness of the mental processes involved in LaBerge's tasks.

Another assumption that is critical to LaBerge's conclusion is the assumption of task comparability, which implies that the nonattention (experimental) and attention (comparison) tasks are comparable (i.e., both tasks are identical except for the deleted processes). In the nonattention task subjects pressed a button whenever a matching pair of letters simultaneously appeared, while in the attention task subjects pressed a button whenever a single letter matched a preceding letter cue. Thus the two tasks cannot, strictly speaking, be considered identical, unless it is assumed that simultaneous and successive letter-matching tasks involve identical processes. Interpretation of the difference between the nonattention and attention tasks would be less tenuous if an identical matching task had been used for both conditions.

Additional evidence pertaining to the validity of the assumption that the two tasks were identical can be acquired through inspection of the reaction time data. One relevant finding is that the response latencies observed in the nonattention task were considerably longer than those latencies observed in the attention task. Indeed, even the familiar letters required approximately 200 msec. longer to be responded to in the nonattention task.

Since the familiar letters are presumed to be automatically processed during the attention switching interval of the nonattention task, the reasons for this 200 msec. difference are not immediately clear. Certainly, it seems unlikely that the attention switching interval requires 200 msec. Thus the processes that take place in the two tasks seem to differ by more than the presence or absence of attention. Possibly a portion of this 200 msec. difference can be attributed to an attentional priming or heightening of the excitability of processing components in the attention task. Unfortunately, this suggestion does not resolve the problem, for the deletion of the attention switching interval would then have to be viewed as influencing the speed of the functioning of the remaining processes. Thus the requirements for the construction of an appropriate comparison task, as discussed above, would again seem not to have been strictly met.

The speed-accuracy problem. Before taking a further look at the relevant experimental data, it will be useful to consider what has come to be known as the speed-accuracy problem. Reaction time is normally assumed to represent the minimum duration required to produce an accurate response. However, when subjects are induced to either lengthen or shorten their response latencies, the number of errors they make changes systematically. Likewise, inducing subjects to vary the accuracy of their performance results in systematic changes in response time. The typical finding obtained in studies which explore this speed-accuracy problem is that as the speed of responding increases, the accuracy of responding decreases (Pachella, 1974; Pew, 1969).

Normally, the information-processing tasks on which response times are used as the dependent variable are so simple that subjects would probably make no errors if they were not rushing their response (Pachella, 1974). Certainly, the subjects in LaBerge's study would have made no errors on the simple letter-matching tasks if they had not been trying to minimize their response times. Thus the average response time obtained on a task might be considered to be the minimum duration required to perform the task, given a specific error rate.

Small variations in accuracy performance can result in relatively large changes in response latencies, particularly on tasks, such as those used in LaBerge (1973a), where the average level of performance is high. This is because subjects may not use the same accuracy criterion on different tasks. Consideration of the speed-accuracy problem can be critical when attempts are made to compare response latencies obtained under different conditions. This, for example, means that findings concerning the response latencies of two tasks that are not performed equally as accurately will be difficult to compare meaningfully.

Thus consideration of both LaBerge's reaction time and performance accuracy data (1973a) is in order. On the first day of testing in the nonattention task, the unfamiliar letters were found to require an average of 48 msec. longer to respond to than the familiar letters. This 48 msec. difference formed one critical part of the data supporting the study's conclusion that only the familiar letters underwent significant automatic processing while attention was switching its focus to the target

letters. Inspection of the performance accuracy data obtained in the nonattention task indicates that a nearly identical, low percentage of errors was made for each type of letter presentation. In light of the above discussion of the speed-accuracy problem, the similarity between these error rates is one important precondition to a meaningful comparison of the two sets of reaction time data.

The finding that the response latencies for the two types of letters were almost equal on the first day of testing in the attention task was critical to the study's conclusion that the unfamiliar letters required an average of only 9 msec. longer to respond to than the familiar letters. However, inspection of the performance accuracy data in the attention task suggests that it may be difficult to make a meaningful comparison between the two types of letter's response latencies. Although the percentage of errors was low on trials where the familiar letters were presented, a considerably higher percentage of errors was made on trials where the unfamiliar letters were presented. Indeed, based on data graphically presented in LaBerge (1973a, Figure 4, p. 27), the present author estimates that the unfamiliar letters resulted in more than twice as many errors as the familiar letters in the attention task.

One interpretation of this difference in accuracy performance is that subjects adopted a different accuracy criterion for each type of letter. If this were the case, it would have grave consequences for LaBerge's conclusions, because the following question would then have to be asked: How large would the difference have been between the average response latencies for the unfamiliar and the familiar letters if the subjects had adopted the same accuracy criterion for both types of letters?

While this question can only be answered in a definitive manner when appropriate empirical data are collected, a prediction can be made based on the speed-accuracy findings reported in other studies (Pachella, 1974; Pew, 1969). The prediction is simply that, if the accuracy criterion for the unfamiliar letters had been as high as the criterion for the familiar letters, the difference between the response latencies of the two types of letters would have been greater. It follows from this prediction that the durations required to process the unfamiliar letters might have been significantly longer than

the durations required to process the familiar letters.

Fortunately, there are experimental procedures that have been used successfully in inducing subjects to adopt specified accuracy criteria (Pachella, Fisher, & Karsh, 1968). These procedures could be used to eliminate the potentially contaminating influence of unequal error rates, should they be found on future studies using LaBerge's general paradigm.

Concluding remarks. A number of useful purposes have been served by the above critical discussion of LaBerge's study. The most apparent purpose was to point out the problematical nature of a few of the central assumptions which must be made before the conclusions of this study can be accepted without qualification. In spite of the above criticism, this study should be considered a valuable initial attempt at elaborating some of the mental processes which seem germane to the acquisition of reading skill. The design of this study was well thought out. Its results were obtained with a commendable precision that is all too often lacking in research on reading processes. Still more importantly, LaBerge's general paradigm appears to provide a flexible model capable of suggesting procedures for studying a number of problems related to the acquisition of efficient reading processes. This latter point will be taken up in more detail below.

A more general purpose also has been served by the above critical discussion. Many of the assumptions that were identified as fundamental to the logic of LaBerge's study must also be made for most cognitively oriented reading research. Use of some form of converging operations seems necessary to study mental events. The general criticism that LaBerge's tasks were not comparable can be directed at most experiments employing converging operations:

> Converging operations, by definition, involve several tasks or conditions that differ from each other in certain systematic ways. They must do this; otherwise they wouldn't converge on some theoretical construct. The argument can thus be made that the converging tasks may involve fundamentally different mediational components (Pachella, 1974: 51).

The perennial nature of criticism concerning the comparability of tasks should not disparage the use of designs using converging operations. Where possible, however, these designs should contain provisions for obtaining data relevant

to the assumptions of comparability. Because it may be impossible to prove that tasks are comparable, all relevant experimental findings must be thoroughly scrutinized for evidence that is inconsistent with critical assumptions. In the case of LaBerge's study, a careful inspection of the data resulted in the identification of findings which appear somewhat incongruous with assumptions of task comparability. However, these incongruities do not provide definitive evidence that the basic assumptions do not hold up. Rather, they provide indications of places where careful scrutiny will be called for in future studies. Additional research using the experimental design used in LaBerge's study should provide evidence needed to clarify questions which are at present ambiguous.

If the experimental paradigm used by LaBerge can be criticized because of its reliance on some rather questionable assumptions, this innovative research design can also be lauded for its potential value as a research tool. The properties of the mental activities which LaBerge examined could not be observed directly; his design seems to provide a means for obtaining relatively precise estimations of these activities. We will turn next to a study (LaBerge & Samuels, 1973) that employs the same general experimental design. A good portion of the criticism directed at LaBerge's study (1973a) could be directed at this new study. As little would be gained from repeating this same criticism, the following discussion will focus exclusively on the general design and positive findings of LaBerge and Samuels (1973).

Automatic Associative Processing

According to LaBerge and Samuels' model, automatic processing can take place at several levels in the processing hierarchy. LaBerge and Samuels (1973) used a design very similar to that used by LaBerge (1973a). A cueing technique similar to the one described above was used to induce the expectation that a particular target would appear. However, in this study, the cueing technique involved a successive word-matching task. The subject was instructed to respond by pressing a button whenever a target word matched the cue word. On occasional trials the presentation of the cue was

followed, not by a word, but by either a familiar or unfamiliar letter. The subject was to name the letter aloud immediately upon its presentation (nonattention task). The letter-naming latency was measured from the onset of the letter to the vocal response which triggered a voice key.

The familiar and unfamiliar letters used in this study were the same ones used in LaBerge (1973a). The naming responses associated with the letters were bee, dee, pea, and cue, respectively, for the familiar letters (*b d p q*) and one, two, four, and five, respectively, for the unfamiliar letters (⊢⌋ ⊢⌉). Because the experimenters wanted response latencies to reflect differences in associative processing instead of letter recognition speeds, subjects were first trained on matching the unfamiliar letters to a point where they were matched as rapidly as the familiar letters under conditions of nonattention. Following this training, the subjects received the first of twenty days of testing in the nonattention task. The termination of each testing period was followed by a period of intensive letter-naming training.

During the first day of testing, the unfamiliar letters took considerably longer to name than the familiar letters in the nonattention task. The results obtained in a comparison task, where the targets were expected, resulted in no difference between the naming latencies for familiar and unfamiliar letters. With additional days of training, the unfamiliar-letter naming latencies gradually became shorter, while the latencies for the familiar letters remained fairly constant. Even after twenty days of training, however, the latencies for the unfamiliar letters remained considerably longer than those for the familiar letters. LaBerge and Samuels (1973) interpreted these findings as supporting the notion that the familiar letters could undergo automatic associative processing to a much greater extent than the unfamiliar letters. The finding that the unfamiliar letters could not be named as rapidly as the familiar letters after 20 days of training suggests that the automation of this form of associative processing occurs very gradually.

An implication of these findings is that beginning readers may be able to carry out associative processing activities only when a large proportion of their attentional resources are allocated to this task. In contrast, skilled readers may be able to carry out this same processing activity

efficiently and automatically. As a result, skilled readers need to allocate only a small portion of their attentional resources to associative processing activities. The attentional mechanism of skilled readers, thus, would be free to focus on other processes.

Additional Applications of LaBerge and Samuels' Research Paradigm

The general experimental design used in LaBerge (1973a) and in LaBerge and Samuels (1973) appears to have considerable value as a research tool. We have already seen how this experimental design has been used to test predictions about automatic processing in letter identification and naming. Numerous additional processing skills, subject variables, training procedures, and distracting task variables could possibly be investigated with this paradigm.

SUBJECT VARIABLES

A variety of subject variables might be investigated by use of LaBerge and Samuels' paradigm. Samples composed of subjects who differ in age, mental ability, or reading proficiency can be systematically manipulated to determine how these groups compare on various types of processing activities. Significant differences between groups may sometimes appear only under conditions of nonattention. Children who are poor readers may not have automated important processing skills to the same extent as their better-reading peers. Additionally, retarded children may generally require more extensive training before they are able to execute processing skills automatically.

The weakness of a skill may not be identified if the skill is assessed at a time when no other skills are simultaneously involved. For this reason, a method is needed to assess how a component skill functions when it is executed concurrently with other processing skills. LaBerge and Samuels' paradigm might be adapted for use in this assessment.

TRAINING PROCEDURES

The influence which various types of training procedures have on the acquisition of automated reading skills

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might be explored. For example, the effects of a few intensive practice sessions could be compared to the effects of several less intensive sessions. The influence that relaxing demands for accurate performance could be investigated. Many of the low-level processes involved in reading may not normally need to be carried out with extreme accuracy, for higher-levels receive considerable redundant information. Additionally, contextual constraints may help reduce the need for accurate low-level processing. Occasionally, when the reader detects a significant discrepancy between his predictions and the results of automatic processes, he might reexamine the visual information more carefully.

DISTRACTING TASK VARIABLES

LaBerge (1973a) and LaBerge and Samuels (1973) used relatively easy matching tasks to control the subject's expectations, thereby preventing him from attending to a particular stimulus. Use of a variety of more complex distracting tasks might provide additional insights. Since reading involves semantic processing, the use of a distraction task that focuses the subject's attention on an activity involving the semantic processing of words might provide results more readily generalizable to reading.

A process is considered to be automatic when its processing activities can be carried out while attention is focused elsewhere. This criterion for automatic processing fails to make differential predictions for the varying influences of different kinds of distracting tasks. Research suggests, however, that when performance decrements on one task result from the concurrent performance of a second task, the extent of the performance decrement is a function of the difficulty of the second task (Keele, 1967). For this reason, the complexity or difficulty of the distracting task per se should prove to be an interesting variable.

Processes that appear to be automated when the distracting task is relatively easy may not appear to be automated when the distracting task makes large demands on limited processing resources (Norman & Bobrow, 1975). When the processing activities involved with an attention distracting task require only a small allocation of limited resources, the remaining surplus of these resources might be sufficient to

allow the operation of a second process. In this situation the second process might appear to be automatic. Yet, when a distracting task involves activities that require a larger allocation of attentional resources, the remaining attentional resources might be insufficient for the operation of a second processing activity. The second process would not appear to be automatic in this case. Thus, a process may appear to require attention in one situation and not to require attention in another.

Alternative Ways to Study Processing Efficiency

EVIDENCE OF AUTOMATIC SEMANTIC PROCESSING

While the experimental approach used by LaBerge and Samuels provides an important means of investigating automatic processing in reading, alternative means are available. One approach that seems likely to provide evidence on automatic processing explores the subject's ability to attend to a task while simultaneously ignoring potentially distracting or interfering semantic information.

Perhaps the best known examples of this type of research involve various forms of the Stroop test. In this test, subjects are instructed to name the colors of the ink in which strings of letters are printed. When the strings of letters spell the names of incongruous colors (e.g., the word "red" printed in blue ink), the color-naming times are slow, relative to the times when the letter-strings spell only nonwords. Since the subjects in this task are attempting to attend to the colors of the letter strings, not to their colors, this color-word interference seems to be due to the automatic reading of the letter strings. The subjects seem unable to avoid automatically processing the interfering words. Color-word interference is not restricted to adults, for it is found for even young children (Schiller, 1966). Apparently the automatic processing of familiar words is learned at an early age (Rosinski, Golinkoff, & Kukish, 1975).

Additional support for the notion that semantic processing can take place automatically is found in a recent study that investigated selective attention in good and poor readers (Willows, 1974). Subjects were instructed to read passages that were typed in black ink. Words that were typed in red ink,

which appeared between the lines in black ink, were to be ignored. When the meanings of the words typed in red ink were congruous with the attended to passage (black ink), proficient readers were found to make more errors involving semantic intrusions of the nonattended words (red ink) than the unskilled readers. Presumably, the low-level reading skills of the proficient readers were highly automated. Their attentional efforts could be focused almost entirely on the meanings of the passage, rather than on the particular colors of the inks involved. As a result, the words printed in red ink, which were automatically identified along with the words printed in black ink, were often adopted as part of the passage when their meanings were consistent with the passage.

TIME SHARING RESEARCH AND THE MEASUREMENT OF EFFICIENT PROCESSING

In recent years, the influence that the performance of one task has on the concurrent performance of a second task (Keele, 1967) has been investigated. The information processing model of Norman and Bobrow (1975), described earlier in this paper, provides a useful theoretical framework for interpreting this research. When the performance of one task interferes with the concurrent performance of a second task, the performance of the second task is considered to be resource limited, i.e., the amount of processing resources allocated to the second task is insufficient for maximum performance. Presumably, performance on the second task decreases as a function of the amount of resources allocated to the first task. This functional relationship between the performances of two tasks can be used to measure the attentional requirements (Kerr, 1973) or processing efficiency of the timeshared tasks.

Therefore, the efficiency of various reading processes can be studied by investigating their influence on a second, concurrently performed task. To be meaningful, however, variations in the performance of the timeshared task must be attributable to variations in the availability of a processing resource of interest. This means, for example, that if we are interested in the extent to which attentional resources are consumed by various reading processes, performance variations on the timeshared task must be attributable to variations in the allocation of attention to this task.

It is assumed that nonproficient readers generally must allocate a larger portion of their attentional resources to reading processes than proficient readers. Thus, as compared to proficient readers, nonproficient readers should experience larger decrements in performance on an appropriate second task that is timeshared with reading processes. In addition, increasing the portion of attentional resources allocated to the reading processes by making the written material more difficult to comprehend, should result in lower performance on the timeshared task. Conversely, increasing the portion of attentional resources allocated to the timeshared task should retard the performance of the reading processes.

Summary and Concluding Remarks

As proficiency in reading is acquired, the numerous component processes involved in reading become increasingly efficient in their use of limited attentional resources. Thus skilled readers need to allocate only a minimal amount of attentional resources to lower-level processes as they read. As a result, their comprehension is normally high, because their attentional resources can be directed almost entirely to the meaning of written passages. In contrast, beginning readers must allocate a considerably larger amount of their attentional resources to lower-level processes. Indeed, for beginning readers the portion of their attentional resources consumed by lower-level activities may be so large that they often pay insufficient attention to the meanings of written passages. As a result, their reading is likely to be awkward and slow, and their comprehension is likely to be low.

The reading model proposed by LaBerge and Samuels (1974) accounts for increased processing efficiency in terms of the automation of various processes. Written information is assumed to undergo processing through a series of component processing stages that involves codes stored in the visual, phonological, episodic, and semantic memory systems. During early stages of skill acquisition, information can be processed through these codes only when assisted by attention. With practice, however, attention becomes dispensable, because much processing can take place automatically. The increasing automation of lower-level processes frees attention to focus on

higher-level processes, such as those involved with comprehension.

Mental events cannot be directly observed. However, their properties can be investigated with experimental designs that employ converging operations. The Subtraction Method is a set of converging operations that has been used to elaborate the role that attention plays in the recognition (LaBerge, 1973a) and naming (LaBerge & Samuels, 1973) of familiar and unfamiliar letters. The conclusions drawn in these studies were as follows: Familiar letters can undergo processing both with and without assistance from attention, while unfamiliar letters can undergo processing only with assistance from attention. In addition, the processing of unfamiliar letters gradually appears to become automated with practice.

These conclusions are consistent with LaBerge and Samuel's reading model. The validity of these conclusions rests on the appropriateness of the Subtraction Method. This method is applicable only when a number of critical assumptions hold up. Unfortunately, empirical evidence for some of these assumptions (i.e., task comparability) is lacking, and LaBerge and Samuels' conclusions cannot be accepted without qualification. This criticism is by no means unique to LaBerge and Samuels' studies, for similar assumptions must be made for most research employing converging operations. Because converging operations of one form or another must be used to study mental activities, care must always be taken to minimize the chances that critical assumptions will be violated. With respect to LaBerge and Samuels' work, additional evidence is needed before their findings can be accepted with confidence. Research applying their paradigm, as well as research employing various Stroop and timesharing procedures, seems likely to yield findings that will help to elucidate the role of automatic processes in reading.

A large portion of the research conducted on reading processes attempts to elaborate the repertoire of subskills possessed by individuals of different reading abilities. However, skilled readers can differ from less skilled readers, not only in the size of their repertoire of subskills, but also in the efficiency and facility with which they are able to execute these subskills. Numerous subskills must be coordinated for reading to take place. Therefore, in addition to identifying the

component processes involved in reading, it is necessary to explore the mental effort that goes into various processing activities.

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The HIP Approach to Reading

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The purpose of this chapter is to critically review the Human Information Processing (HIP) approach to reading. An attempt will be made to assess its utility both as a theory of how people read and as a possible guide to pedagogical practice. The acronym is particularly appropriate because the HIP approach is also the "hip" approach, in that it is currently the dominant paradigm in cognitive psychology, one branch of which is the psychology of reading.

In this brief critique there will be no attempt at a comprehensive survey of all information processing models of reading as this has been done elsewhere (Geyer, 1972; Smith & Spoehr, 1974; Massaro, 1975) and the models proliferate so rapidly that no review can remain up to date for more than a month or so. The first question which arises is, what is the HIP approach and how does it differ from other approaches? In his 1967 book, which served as early manifesto for the HIP approach, Neisser stated that the goal of the approach was to describe the human information processing system in terms of "all the processes by which sensory imput is transformed, reduced, elaborated, stored, recovered and used." This covers such traditional areas as sensation, perception, memory, problem solving and thinking and even such fringe areas as imagination and hallucination. A parallel aim was to describe these processes in a precise and formalistic way, a sort of search for the "algorithms of the mind." In service of this aim, the information processing analogy was borrowed from computer science. This had a number of consequences. Since computers can compute but can't comprehend, computation time, rather than some measure of understanding, became the primary dependent variable. Response latency was looked

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upon as a window on the workings of the mind via the additive and subtractive reaction time methods discussed by West in this volume. Flow charts became de rigueur and mental processing was seen as deterministic, rather than probablistic, localized rather than diffuse, indirect rather than direct, physically mechanistic rather than biologically squishy, and discrete rather than continuous. Each of these assumptions of the HIP approach have currently come under heavy attack (Shaw & McIntyre, 1974; Shaw & Bransford, 1977; Turvey, 1977), although no new paradigm has yet arisen to displace the HIP approach from its position of dominance in cognitive psychology.

The HIP approach to cognitive psychology may turn out to be a dead end because like other past formalistic approaches, such as transformational grammar, information theory, and mathematical models, it attempts to deductively postulate how things should be rather than inductively attempt to account for how things actually are. Even early proponents of the HIP approach are having second thoughts. Thus Neisser (1976) in his most recent book on cognitive psychology concludes:

> Such optimism (concerning the HIP approach) may have been premature. The study of information processing has momentum and prestige, but it has not yet committed itself to any conception of human nature that could apply beyond the confines of the laboratory. And within the laboratory its basic assumptions go little further than the computer model to which it owes its existence.

Since most experiments in the HIP tradition have used alpha-numeric and linguistic stimuli, it is in a better position to claim to account for reading than for perception of the natural world; but even here serious questions of its ecological validity arise.

The HIP movement isn't monolithic in its approach to modeling the reading process. Goodman (1970), whose major empirical contribution has been an analysis of naturalistic observation of children's oral reading errors, has proposed a comprehensive model of reading which is couched in HIP format with an elaborate flow chart. A similar elaborate complete model has been proposed by Mackworth (1972). These models have been critcized by Calfee (1974) as Gestalt or Jello

models which quiver all over wherever they are touched. A major claim of the classic HIP approach is that it is capable of specifying the discrete components and subprocesses which composed the information processing system. Calfee (1977) has advocated the use of the additive factor design (see West, this volume) to determine independent component and subprocesses. This procedure will only work with rather simple sequential models such as that proposed by Sternberg (1969). It clearly won't work if there are complex interactions such as feedback loops, and parallel processes, as in the Goodman (1970) and Mackworth models (1972).

The complexity of the model proposed is, of course, almost directly proportional to the complexity of the phenomenon it was designed to explain. Goodman (1970) for example states:

> I offer no apologies for the complexity of this model. Its faults lie not in its complexity but in the fact that it is not yet complex enough to fully account for the complex phenomena in the actual behavior of readers.

The classical HIP response to this problem is to drastically simplify the task environment. Simon (1969), a leader of the HIP approach, states the case:

> A man, viewed as a behaving system, is quite simple. The apparent complexity of his behavior over time is largely a reflection of the complexity of the environment in which he finds himself.

This preference for simple models and simple tasks was also stated by the National Institute of Education panel on modeling the reading processes.

> Advances in understanding of the reading processes have come primarily from narrowly delineated areas in which models are easily constructed and tested (Venezky, Massaro, & Weber 1976: 691).

This preference for simplifying the task environment leads most HIP investigators to use single words or even letters as stimuli and to use tachistoscopic recognition threshold and reaction time tasks. It takes a large leap of faith to believe that results obtained in these tasks are in any direct way related to the processes a reader uses in everyday reading for meaning.

Indeed as the research literature develops it appears that the results obtained are not only specific to the particular task used but are also dependent on very small changes in experimental procedure or on the subjects' strategies which are often not under direct experimental control.

To demonstrate this point it will be instructive to briefly review the most "important" issues in the experimental literature on reading from the perspective of the HIP approach. The first issue is the controversy over the unit of processing in reading. Various HIP models have proposed almost every alternative from single letters (Gough, 1972), spelling units (Gibson et al., 1972), syllabic "vocalic center groups" (Spoehr & Smith, 1972), to words (Smith, 1971). The three major lines of evidence bearing on this controversy are: a) the lower tachistoscopic recognition threshold for letters embedded in words compared to letters in isolation (Reicher, 1969; Wheeler, 1970); b) the superiority of recognition of words over nonwords; and c) the effect of word length on word recognition. Although these effects are obtained in some experiments, they are not obtained in others which differ only slightly in procedure or response measure used. After an extensive review of this issue in the HIP word recognition literature, Smith and Spoehr (1975) concluded that the extreme variability of results is dependent on small methodological differences in the various experiments which affect the subjects' processing strategies.

A second related issue is the route to lexical access of word meaning, often posed in the form of a question, "is phonemic recoding necessary?" (See Ehri, Barron, & Feldman [1978] for a review of the experimental literature on this issue). This issue is also unresolved and probably is unresolvable for reasons which are similar to those discussed previously. A major methodological problem in the literature on this issue is that visual familiarity is often confounded with phonemic encodibility. Since this is also true in the natural environment of printed language, those studies which claim to unconfound these factors tend to use tasks which are far removed from reading for meaning (e.g. the lexical decision task used by Meyer et al., 1974). It appears that the closer the research task gets to normal reading the greater the influence of speech processes in reading (Klieman, 1975; Levy, 1975, 1976).

Kathyrn Spoehr (1976) has recently concluded that the phonemic encoding debate is also a psuedo-issue. She demonstrated that subjects will use a phonemic strategy under some conditions and a visual strategy under other conditions (e.g., when the visual icon is not available either because the masking stimulus is used or a delayed report is required).

Overall it appears that the research situation in word recognition has not changed appreciably from that in the past decade when Neisser (1967:105) concluded:

> In the last twenty years, psychologists have made tall mountains out of several molehills with discouraging results.

The only significant change in the past decade is the nature of particular molehill issues on which mountains of data have been collected.

To what extent can the existing HIP models account for the variation in strategies? The earliest HIP models of reading, such as Gough's model (1972), tended to be simple sequential "bottom up" models. Although endowed with a number of mystical boxes such as Merlin and TPWSGWTAU (the place where sentences go when they are understood), Gough's model made a number of potentially testable assumptions (e.g. that single letters are the unit of processing). However it did not allow for variation in strategies as a function of task requirements because processing at a higher level depended completely on processing at the lower level immediately preceding.

The LaBerge and Samuels model (1974), discussed by West in the previous paper in this volume, is somewhat more flexible in that there are multiple alternative pathways for processing. This flexibility however is gained at the expense of testability since there is no clear mechanism to account for when or why one pathway is chosen over another. The LaBerge-Samuels model is also essentially a bottom-up model and although the attention mechanism allows for some selection, it is not clear how this attention mechanism operates. The major concept in their theory—automaticity—really lies outside the model and seems to be only a restatement of Thorndike's dictum that "practice makes perfect." As Rumelhart (1976) has pointed out, no strictly "bottom up" model can account for effects of context on the perception of

printed language. These include the effects of surrounding letters on letter perception, the effects of surrounding words on word perception, and the effects of paragraph context on sentence comprehension. All these effects require some "top down" capacity in that the analysis at the lower level must be at least partially dependent on higher levels of analysis. Rumelhart (1976) has proposed an "interactive" model of reading in order to account for the effects of context on processing at the lower level. This model assumes that all processing is interactive and takes place in some large central processor. Information from orthographic, lexical, syntactic, and semantic systems contributes to a recognition or comprehension response in some mysterious fashion. Needless to say such a model can no longer deliver on the HIP promise for a description of the independent component sub-processes which make up the processing system. It is in Calfee's "Jello model." So we are back where we started.

Models such as the Rumelhart model also cannot account for differences in performance as a function of differences in processing strategies which seems to be ubiquitous in the literature. This requires some "executive control" or "central processor," but it must be clear that these are merely labels for homunculi whose own processing algorithms must in turn be explained if they are not to be the "ghost in the machine," or unless there is to be an infinite regression of homunculi (Shaw & Bransford 1977: 7).

In summary the HIP approach appears to be a restricted formalism which, although it has been heuristic in producing a narrow research literature, is in no immediate danger of accounting for normal reading even in proficient readers. If it is not even able to consistently account for the experimental phenomenon in such artificially and ecologically peculiar tasks such as reaction time and tachistoscopic recognition, we can scarcely look to the HIP approach for any suggestions for a pedagogy of reading, particularly since current HIP models generally have no way of dealing with individual differences either as a function of developmental level or at the same developmental level. There is plenty of evidence that children learning to read process print differently than adults (Doehring 1976; Marsh, Desberg, & Cooper, in press; Santa, 1977) and

that even adults who are proficient readers differ in their processing strategies (Barron & McKillop, 1975; Rundle, 1970). It is probable that proficient adult readers also have a large repertoire of strategies which can be deployed depending on the task requirements. This has led Gibson and Levin (1975), after surveying various models of reading, to conclude:

> If there is no single reading process, but instead many reading processes there can be no single model for reading. Either one must construct many models, or instead take a different approach, seeking for some general principles that will apply, given the many variables of task and information to be considered. The latter strategy is the one we have adopted (Gibson and Levin, 1975: 438; see also Gibson, in press).

In conclusion, when we consider the HIP promise to deliver a precise description of the Human Information Processing system and attempt to apply this approach to the understanding of reading as a cognitive process or guide to pedagogy, we are forced to conclude that research in this area has tended to follow George Bernard Shaw's description of the specialists who "know more and more about less and less until they will know everything about nothing."

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